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Computer Simulation of the EPA Provisional Method for Measuring Airborne Asbestos

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COMPUTER SIMULATION OF THE EPA PROVISIONAL METHOD FOR MEASURING AIRBORNE ASBESTOS

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FOREWORD

Measurement and monitoring research efforts are designed to anticipate potential environmental problems, to support regulatory actions by developing an in-depth understanding of the nature and processes that impact health and the ecology, to provide innovative means of monitoring compliance with regulations, and to evaluate the effectiveness of health and environmental protection efforts through the monitoring of long-term trends. The Environmental Monitoring Systems Laboratory, Research Triangle Park, North Carolina, has responsibility for: assessment of environmental monitoring technology and systems; implementation of agency-wide quality assurance programs for air pollution measurement systems; and supplying technical support to other groups in the Agency, including the Office of Air, Noise, and Radiation, the Office of Toxic Substances, and the Office of Enforcement.

Planning this investigation was conducted at the request of the Office of Air Quality Planning and Standards. A computer method was developed to determine the accuracy of EPA's provisional methodology for measuring airborne asbestos fibers. Asbestos is the most widely used material for insulation, as well as for a variety of other applications. However, in these processes, there are levels of asbestos loss into the environment that pose a significant health risk. It is, therefore, pertinent to assess the reliability of human estimates of asbestos levels. Computer simulation can be used to identify the error factor for the purpose of correcting future estimates.

ABSTRACT

A computer simulation program was developed to reproduce manual counting methods and calculate their accuracy in estimating the number of asbestos fibers on a filter surface. A model arrangement of asbestos fibers on a filter was generated for a predetermined number of fibers with lengths and widths according to lognormal distribution and uniformly random placement. These hypothetical fibers were next counted by computer in a program simulating manual microscopy estimating procedures. The protocols proved to have a quantifiable error factor when the computer counting results were compared with the predetermined, original total of model fibers. The bias resulted because, in the counting protocol, fibers on the sample grid having an aspect ratio less than 3 were not included. The mass estimates proved correct at light loadings but were biased low at heavy loadings. It is suggested that most of the mass is concentrated in the large fibers; thus, at light loadings these fibers are well sampled due to their size. At heavier loadings they are more likely to extend past the field of view and their size is more likely to be underestimated.

INTRODUCTION

This report describes a computer simulation of the EPA provisional method for measuring airborne asbestos.

The unique physical properties of asbestos have encouraged widespread use of this mineral for centuries in a variety of applications. A large industry has developed around usage of asbestos as a result. Unfortunately, prolonged exposure to airborne asbestos fibers adversely affects the respiratory system by reducing lung capacity and recent studies have related various forms of lung cancer to asbestos exposure. The Environmental Protection Agency (EPA) has moved to control emissions of asbestos because of its widespread use and hazardous nature.[1] Because of the diffculty in controlling all sources of emissions, the need exists to monitor airborne asbestos.

Airborne asbestos fibers range in length from a few micrometers down to submicron sizes. Median airborne fiber lengths reported in the literature range from about .5 μm to as much as 5.0 μm[2,3] and are best measured using electron microscopy. Asbestos fibers are identified by morphology, chemical composition, and crystal structure. Morphology is determined by direct observation under the microscope. Chemical composition is determined by x-ray fluorescence. Crystal structure is determined by selected area electron diffraction.

The EPA provisional methodology for measurement of airborne asbestos employs samplers ranging from high volume using 8" x 10" filters to personal samplers containing circular filters 37 mm in diameter. Transmission electron microscopy (TEM) is used to identify and measure airborne fibers. Because several charactersitics of fibers are considered in health studies, fiber count, length, width, and mass are reported. Collecting fibers on filters presents the fewest problems in the measurement process described in the provisional method; however, microscopic analysis of the filters presents many problems. The method is an uneasy compromise between statistical sampling and TEM microscopy. The statistician worries about analyzing a large enough portion of the filter to make meaningful estimates, while the microscopist worries about analyzing a sample that is small enough to complete the job under time and budget constraints.

Following collection of fibers, a circular section 3 mm in diameter is removed from the filter for TEM analysis. The section is placed on a TEM grid to identify positions in the sample, where up to 10 grid openings (75 to 100-μm squares) are examined according to a strict counting protocol. Fiber counts on the filter are estimated from fiber counts in the sample section

multiplied by the ratio of filter area sampled to total filter area. This ratio is usually in the neighborhood of 10,000. The importance of a well conceived counting protocol is obvious.

Testing the counting protocol has been accomplished by repeated experimental observations by TEM which are tedious, time consuming, and expensive. This report describes a computer simulation of the counting protocol. The program used IMSL[4] and TEKTRONIX software and hardware.

CONCLUSIONS

Several assumptions are made in the simulation model which make it a valid approximation to reality, although preliminary, and subject to later modifications. These assumptions will be discussed in more detail later in the paper. The simulation model has identified the following problems with the provisional method of counting asbestos fibers.

- An aspect ratio (length to width) of 3 or less was chosen as the cutoff point below which an object is not counted as a fiber. However, as a result, the method underestimated both fiber count and mass in all the simulation runs to date except when a filter had a small number of fibers on it (light loading); then the fiber mass estimates reflected no bias. One possible explanation for this seeming discrepancy is that most of the mass is concentrated in the larger fibers. With fewer fibers to count, more of the large ones are likely to be counted and measured. With heavier loadings, more large fibers are likely to be cut off at the edge of the view field and thus to be measured too short.

- The number of fibers that must be counted in the medium loading protocol make it difficult to identify enough random fields of view within a grid opening to follow the protocol.

- The size of a field of view varies according to the manufacturer of the microscope. The smaller fields of view (less than 5 μm squares) cause serious truncation of fiber length distributions and compound the problem of defining enough random fields of view to follow the counting protocol.

- A problem inherent in this kind of sampling pertains to the higher probability of larger fibers to show up in a random sample. Not every fiber has an equal chance of being sampled. This factor is recognized as sampling with probability proportionate to size (PPS). Because the protocol in this research does not fit the standard form of PPS sampling, the problem of variable probability still needs to be addressed.

RECOMMENDATIONS

The following underlying assumptions in our model should be reconsidered and allowances made for possible exceptions.

For purposes of the simulation, it has been implicitly assumed that fibers do not bend. In reality, most airborne fibers do appear to hold their rigidity. However, some do not. It would be difficult to design a program so that fibers would bend smoothly as they do in photographs. However, a first approximation has been suggested. The smooth bend could be approximated by a single sharp bend at a random angle and at a random point along the fiber. This modification will be considered in the future if time is available.

A somewhat controversial question in terms of this model regards the status of fibers as having an aspect ratio of 3 or less. Some asbestos researchers feel that objects of this size are not harmful and are not really fibers.[5] Asbestos tends to exhibit perfect lengthwise cleavage into fibers or fiber bundles. Therefore, according to this school of thought, a high length to width ratio is a necessary criterion for a mineral to be called asbestos. Minerals with identical crystalline structure and chemical properties but nonfibrous in nature would not be considered asbestos. It is possible that our cutoff value of 3 is too small and should be increased to 10. This issue could be handled in the model by probability calculations for an object's being a fiber with an aspect ratio of 3 or less.

The final assumption that needs to be modified for possible exceptions is obviously unrealistic: there are no operator errors in following the protocol or in measurement and identification.

EXPERIMENTAL

SIMULATION MODEL

The model has been constructed appoximate reality on the basis of initial simplifying assumptions. It generates a predetermined number of "realistic" fibers according to conditions of randomness, then counts this pregiven total by the provisional counting method.

Fibers are generated in random amounts, placement, and shapes for the simulation. The fibers are rectangular objects (cylindrical in reality) whose lengths and widths are distributed nas bivariate lognormals.[6,7] First, two normal distributed random variables are drawn with a mean of zero and a variance of one, then transformed to the following bivariate distribution:

$$f(\ell\omega) = \frac{\text{EXP}\left\{-\left[\frac{(\log\ell - \mu_\ell)^2}{\sigma_\ell^2} - \frac{2\rho_{\ell\omega}(\log\ell - \mu_\ell)(\log\omega - \mu_\omega)}{\sigma_\ell\sigma_\omega} + \frac{(\log\omega - \mu_\omega)^2}{\sigma_\omega^2}\right] \Big/ 2(1 - \rho_{\ell\omega}^2)\right\}}{2\pi\sigma_\ell\sigma_\omega\sqrt{1 - \rho_{\ell\omega}^2}} \quad (1)$$

The bivariate distribution used in the program appears in Figure 1. Values are: $\mu_\ell = -.3$, $\mu_\omega = -1.07$ $\sigma_\ell = 1.42$, $\sigma_\omega = .4$, and $\rho_{\ell\omega} = 0.53$. These parameters place the distribution in the reported range of sizes of airborne asbestos samples.

Although a fiber has been generated in this manner, it is placed on the filter at random. This placement is accomplished by drawing two uniformly distributed random variables which define coordinates for placement of the

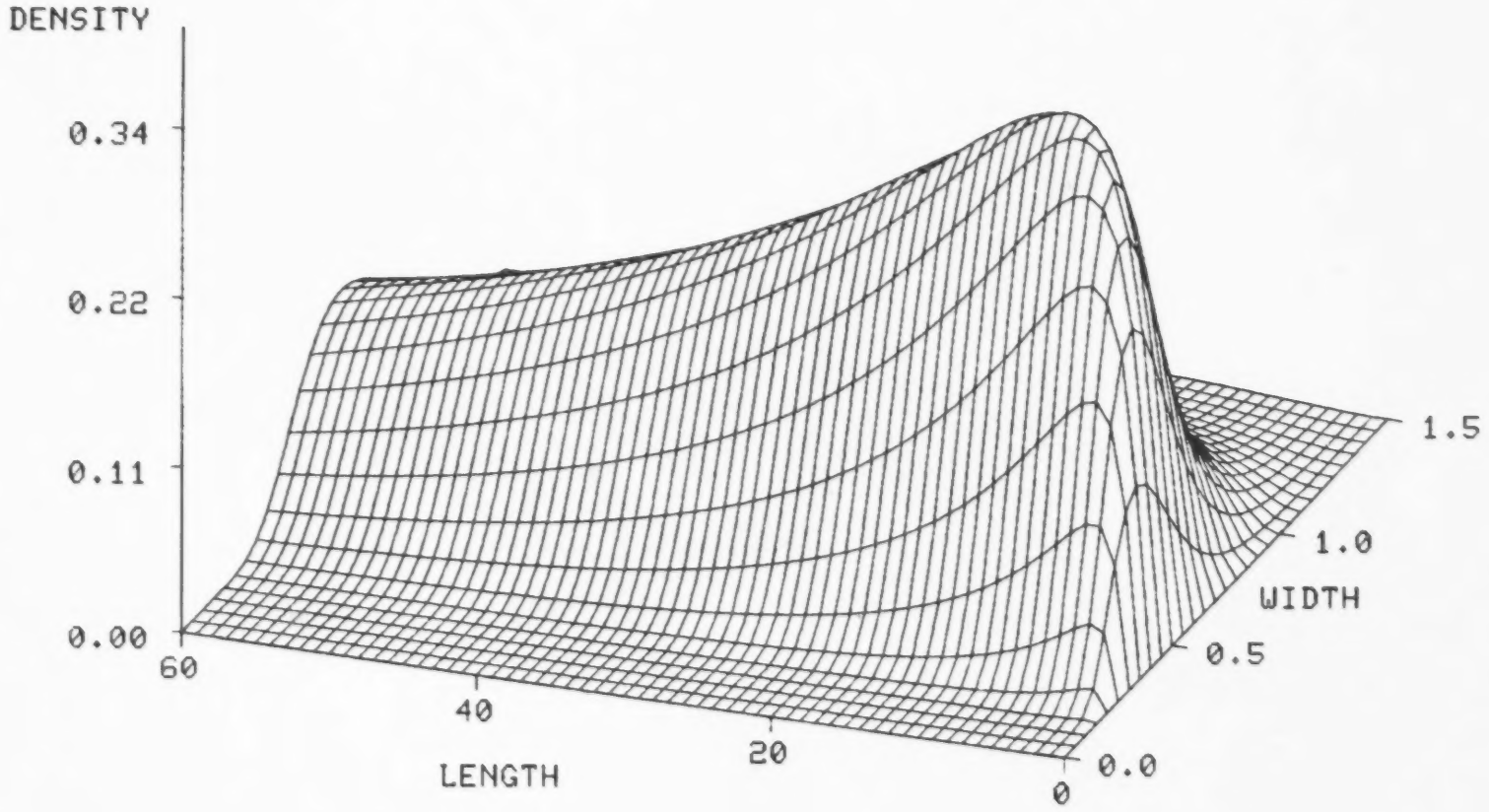

Figure 1. Bivariate lognormal distribution from EPA simulation model of airborne asbestos.

fiber. The origin and alignment of the coordinate system is randomly located with respect to the filter surface. The fiber is then oriented by drawing a third uniformly distributed random variable to define an angle of rotation for the fiber. By knowing the fiber length, width, placement, and orientation, the coordinates for any corner of the rectangle can be computed. As the fibers are created, various statistics are accumulated to compare with the results of the analysis.

The counting protocol[8] is then followed exactly. First, a circular section 3 mm in diameter is defined at random on the surface of the filter in the same way fibers are distributed. However, a placement will be rejected if it is any closer than 1 mm to the edge of the filter. A grid within the section is defined, with a randomly placed starting value and a random orientation. This also is accomplished in the same way that fibers are placed and oriented. Since the protocol allows for a maximum of 10 grid openings, 10 of the available grid openings are selected at random. Coordinates of the two end points of each fiber are checked to see if it falls within one of the 10 randomly selected grid openings. If so, the information concerning that fiber is stored for future sampling. The counting protocol is defined in the following steps:

- Preliminary count - The first grid opening selected is counted. If the number of fibers counted is greater than 300 fibers, the sample is said to have heavy loading, and no further analysis is performed since the method calls for ashing, dispersing, and refiltering the sample and starting over. If the number of fibers counted is less than 50, then the sample is said to have light loading and the light loading protocol is followed. Otherwise (50< count <300), the sample is said to have medium loading, and the medium loading protocol is followed.

- Medium loading protocol - A field within a grid opening is defined at random. The fields of view are oriented once at random and placed in the same way fibers are laced. Fields of view are not allowed to overlap grid opening borders or each other. A fiber is recorded and measured only up to the edge of the field of view, even though the length may thus be truncated. The aspect ratio is checked, and if less than 3, the fiber is not included in the count. If the fiber extends beyond the field of view, it is only given a half count. Other fields of view are selected until the fiber and fields of view are defined within it. This process continues until at least 100 fibers have been counted or 10 grid openings have been selected.

- Light loading protocol - The only difference between medium and light loading is that the entire grid opening is examined instead of single fields of view. Counts are made and new grid openings are selected until 100 fibers are counted or 10 grid openings have been examined.

RESULTS

Example

In the example run, the parameters used for the bivariate distribution were $\mu_{\log \ell} = -0.3$, $\mu_{\log \omega} = -1.07$, $\sigma^2_{\log \ell} = 1.42$, $\sigma^2_{\log \omega} = 0.4$, $\sigma_{\log \ell \omega} = 0.53$. The density of fibers was specified as 20,000 fibers mm^2. A circular filter, 10 mm in diameter, was used. There was a microscopic field of view of .01 mm or 10 μm on a side, with grid openings of .075 mm or 75 μm on a side. A numerical total of 1,570,779 fibers was generated and depicted on the filter. Their average length was 1.59 μm, average width 0.1604 μm, and total mass 0.0025320815.[8]

Graphics output from the program depicting placement of the circular sample section is found in Figure 2. The section contained 1200 fibers. A first count showed that the filter had medium loading and that the first grid opening had 91 fibers in it. An example of the counting protocol is found in Figure 3. It contains the 11th field of view picked for the first grid opening, with three fibers visible in the grid opening. These are the 29th, 30th, and 31st fibers in order of observation from the beginning of the counting. The 29th fiber has an aspect ratio of 6.9 and is completely within the field of view. Therefore, it was counted as 1. Fiber number 30 has an aspect ratio of over 70. However, this fiber runs off the field of view. Therefore, it was only given a half count. Fiber number 31 has as aspect ratio of 1.1 and was, therefore, not counted as a fiber. Figure 4 shows the placement and selection of the grid openings and fields of view within the selected grid openings.

Estimates for the filter were 1,161,023.4 total fibers for the filter. This was a 26% underestimate of the true fiber count. The estimated mass in the filter was .002123 g, a 16% underestimate of the true mass on the filter.

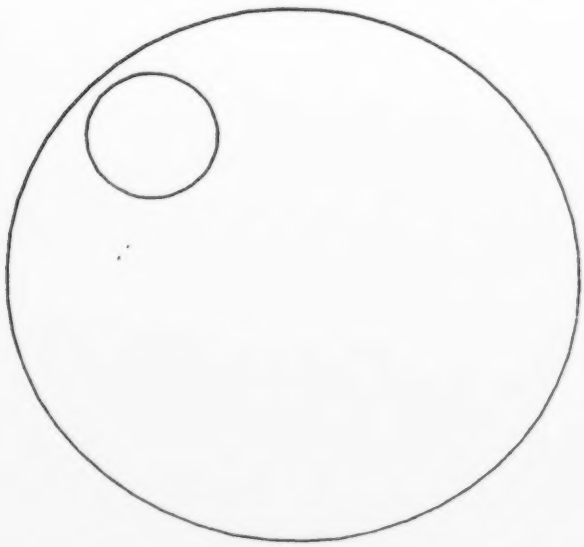

FIGURE 2. Placement of circular section containing asbestos fibers on TEM grid.

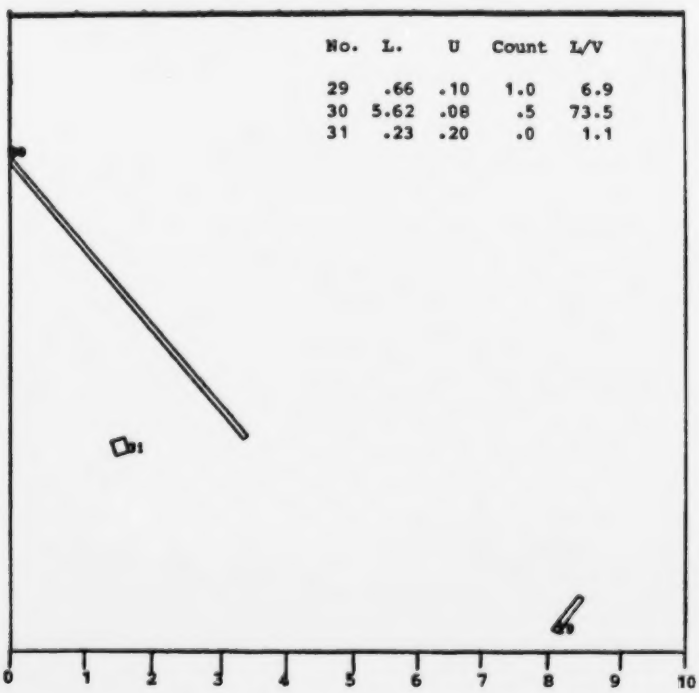

FIGURE 3. Example counting protocol showing view field 11 in grid No. 2, three fibers, length and width in NM, positions 29, 30, and 31.

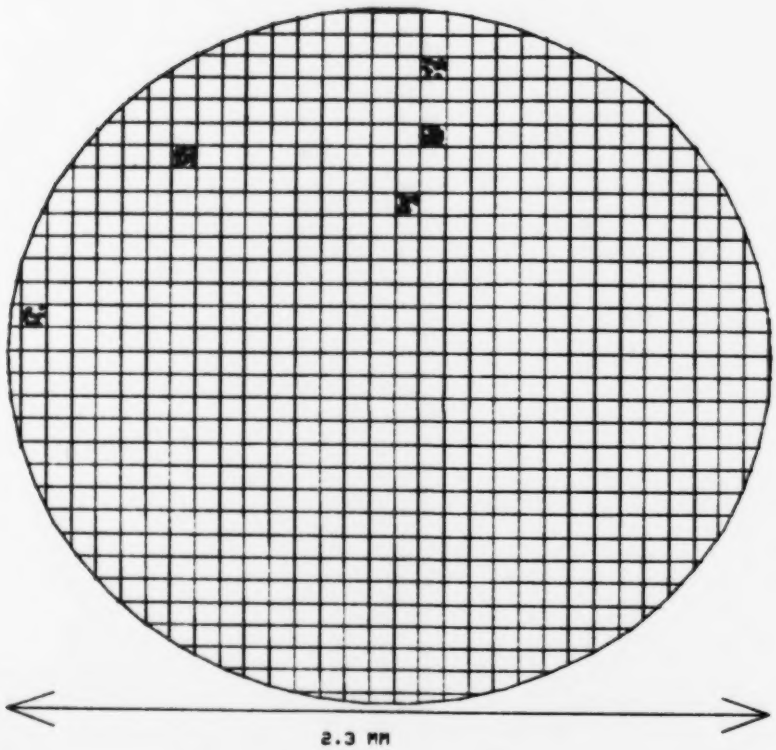

FIGURE 4. Placement of grid openings and fields of view within selected openings.

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